Aeolus – 1st wind lidar in space

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T. Parrinello and D. Wernham - on behalf of the Aeolus team

Outline

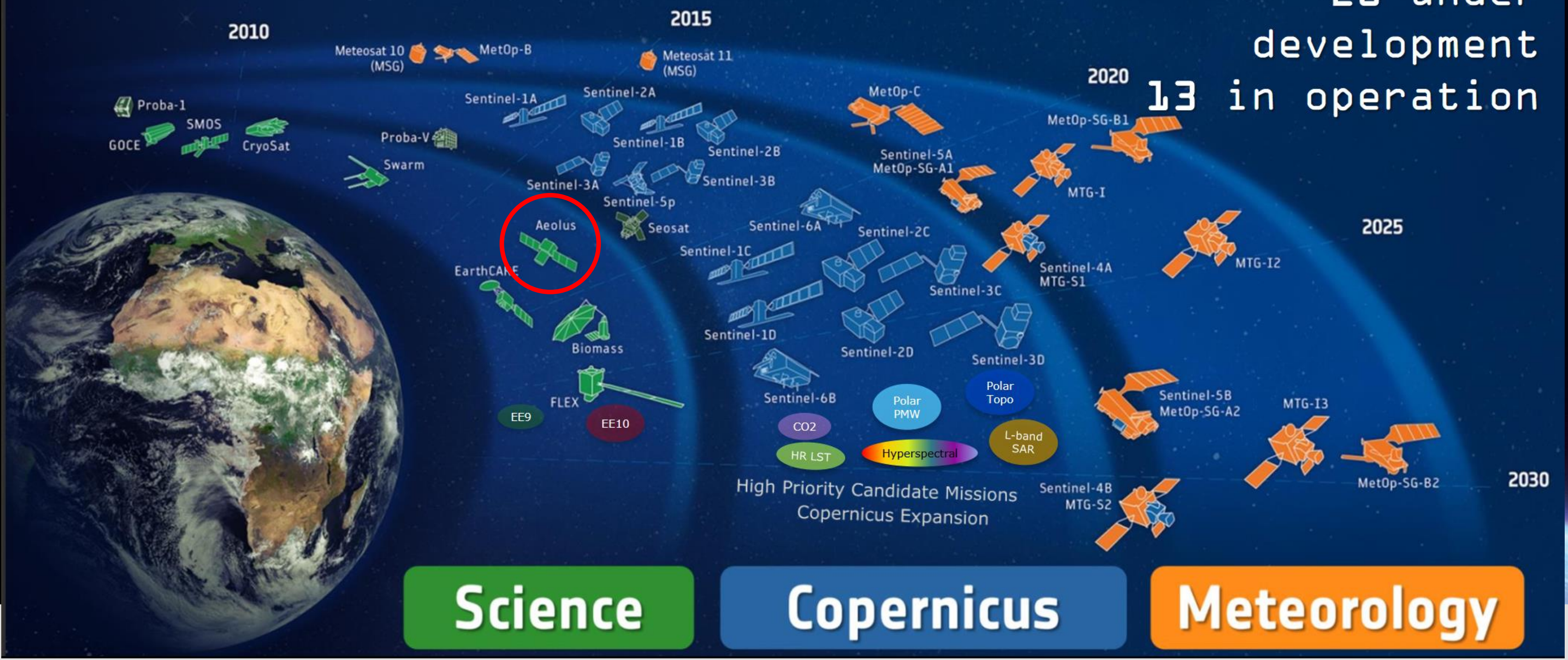
Objectives

Aeolus-Mission

First year in space

ESA-DEVELOPED EARTH OBSERVATION MISSIONS

Satellites
28 under development
13 in operation



(1) Objectives

Scientific objectives

- Improve the quality of weather forecasts
- Advance the understanding of atmospheric dynamics and climate processes

Explorer objectives

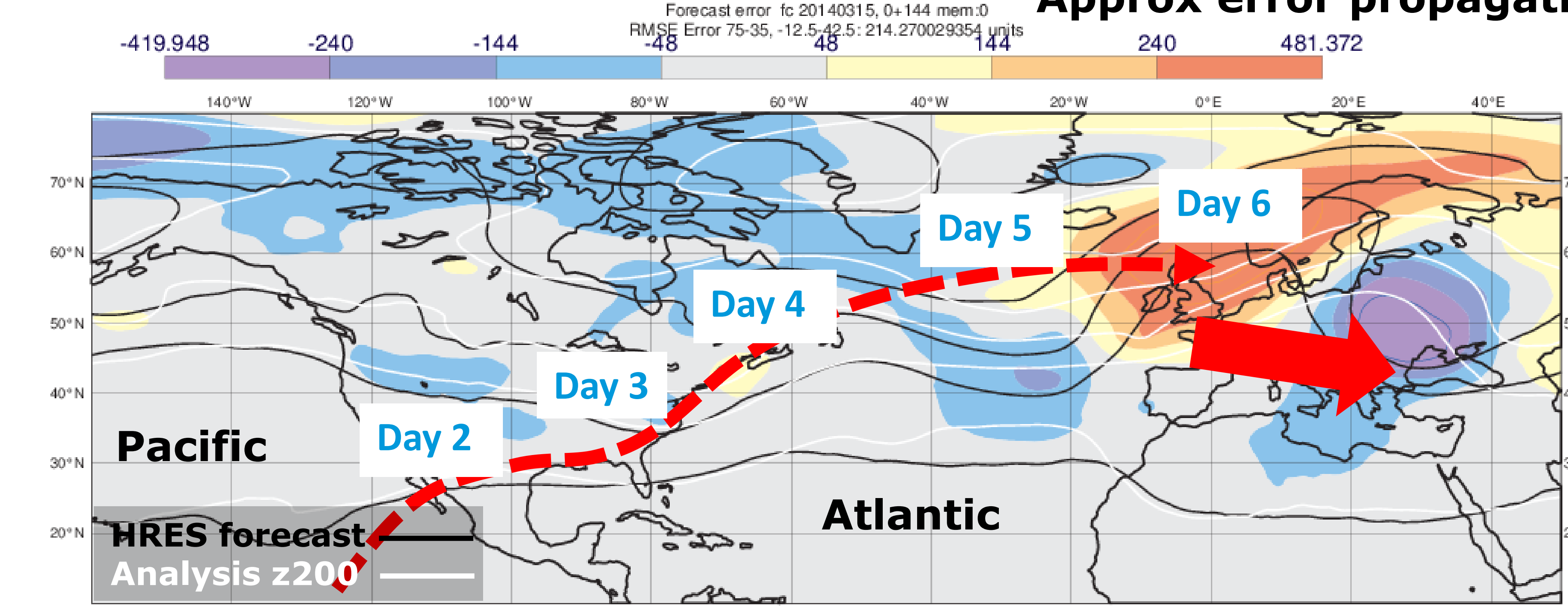
- Demonstrate space-based Doppler Wind LIDARs potential for operational use

Observation means

- Provide global measurements of horizontal line of sight (HLOS) wind profiles in the troposphere and lower stratosphere

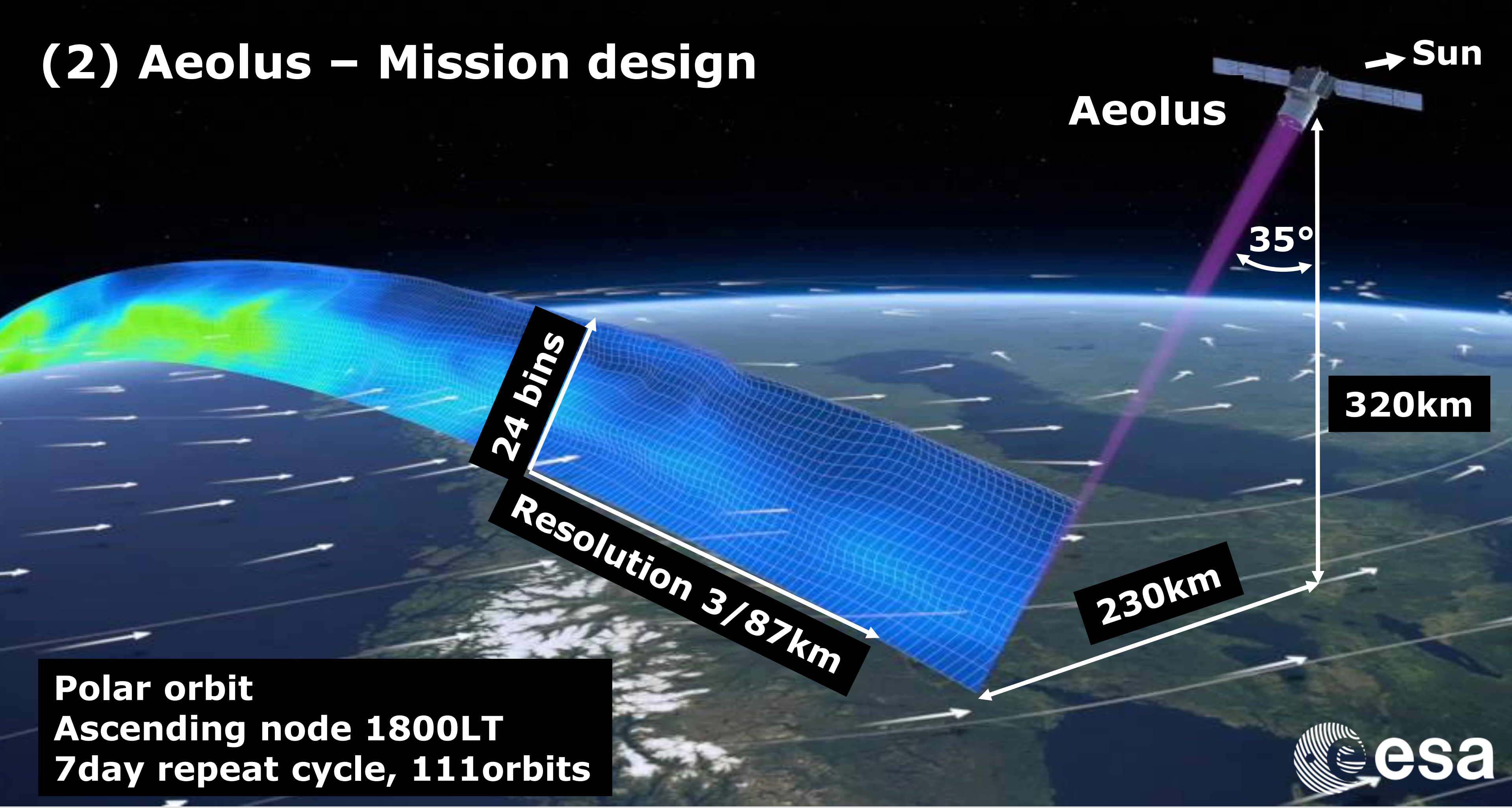
(1) Forecast bust, Europe 03/14

Approx error propagation

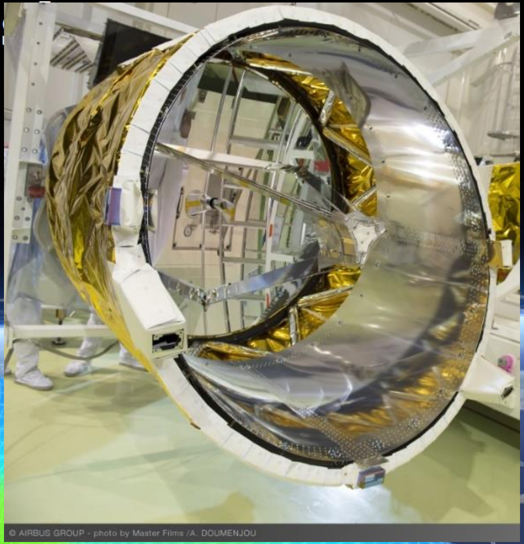


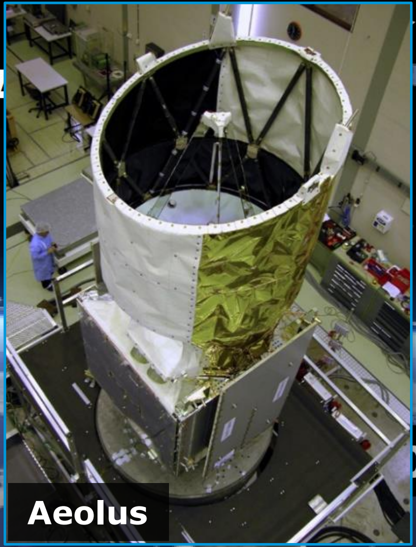
Magnusson, 2017

(2) Aeolus – Mission design



Polar orbit
Ascending node 1800LT
7day repeat cycle, 111orbits

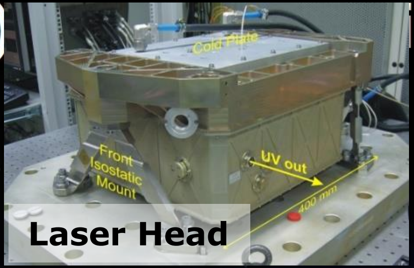


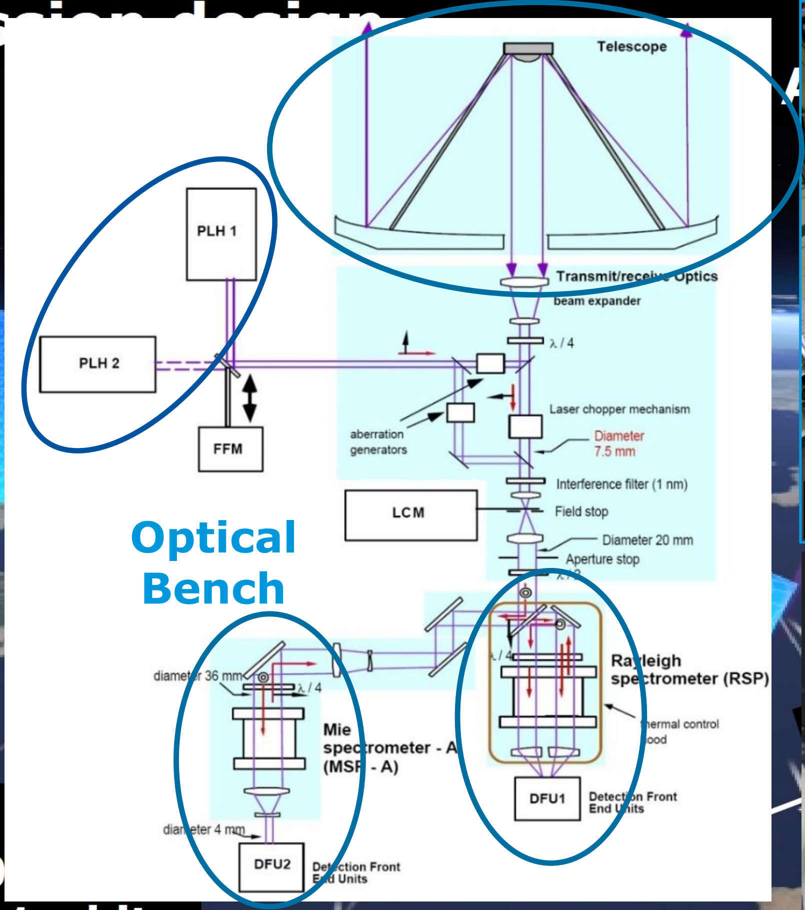


Telescope

- 1.5m diameter
- Cassegrain type
- SiC structure

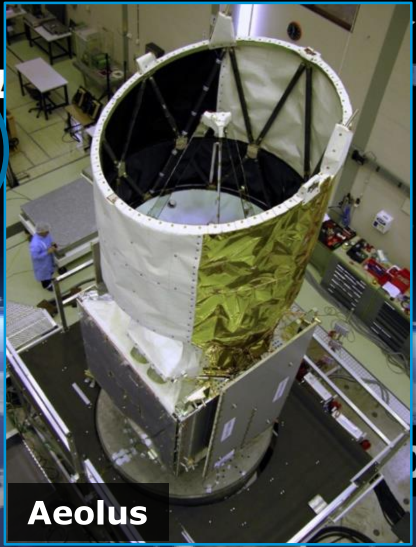
(2) ssion design

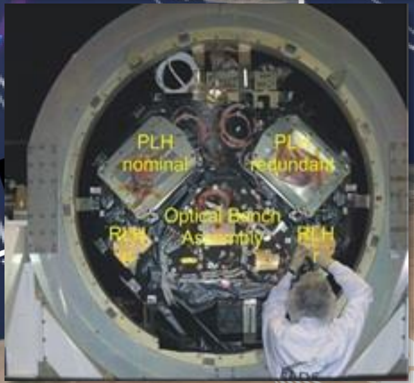




Sun

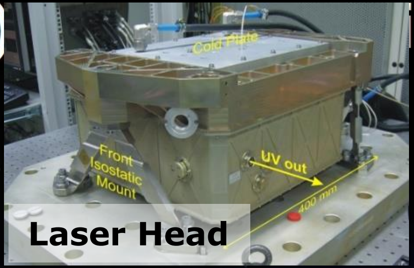
0km

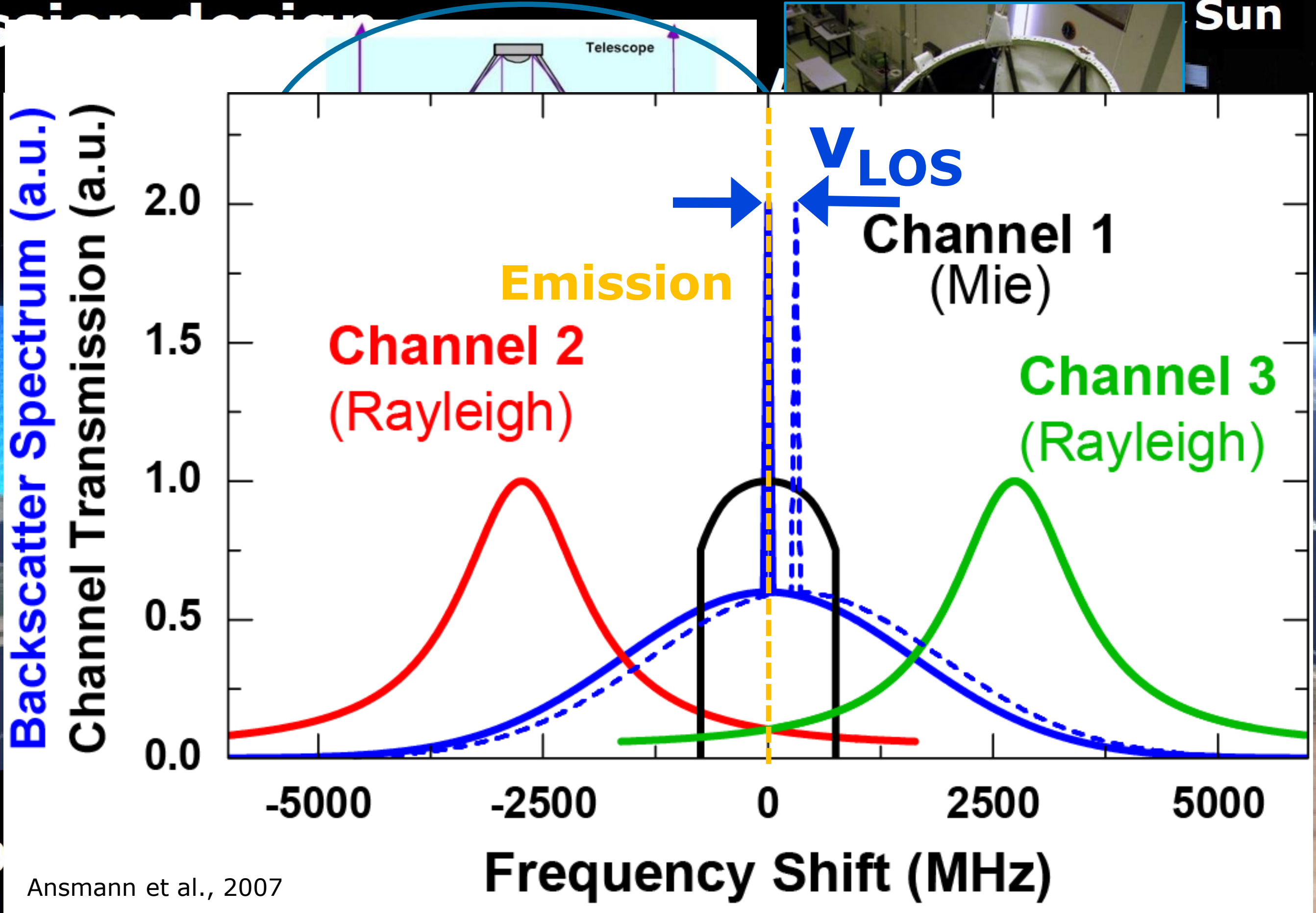




Pol
Asc 0
7da 11orbits

(2)



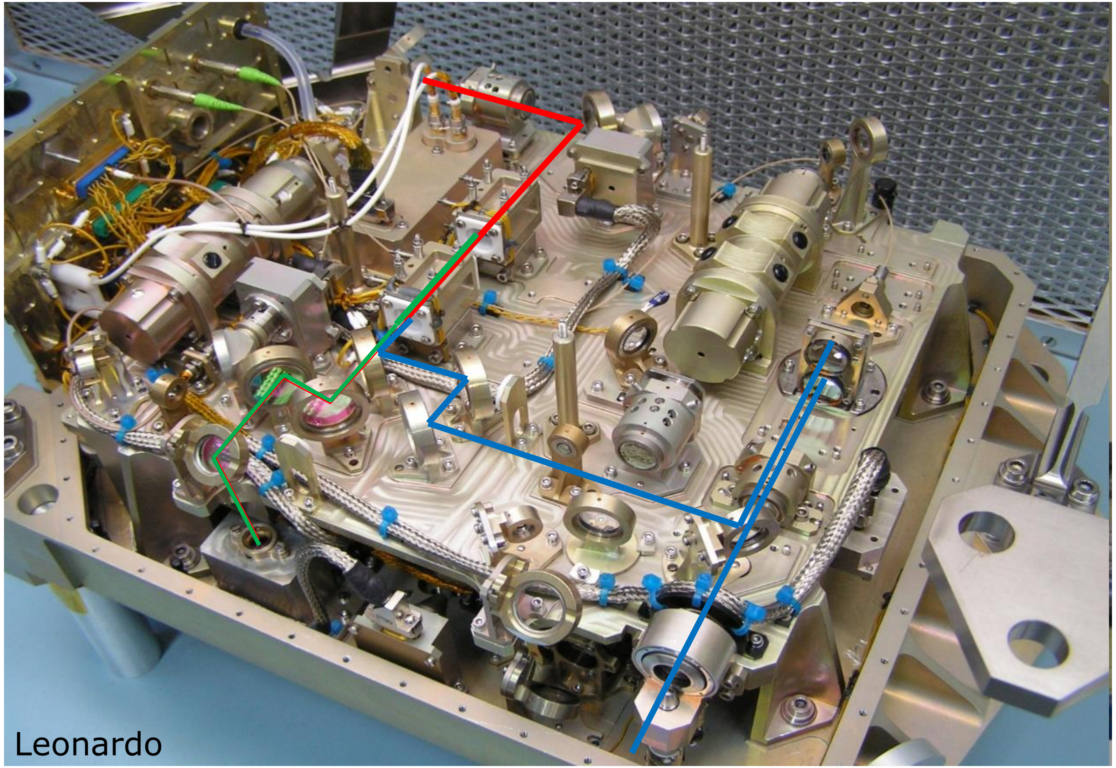


Ansmann et al., 2007

Sun

Pol
Asc
7da

(2) Aeolus – ALADIN (Atmospheric Laser Doppler Instrument)

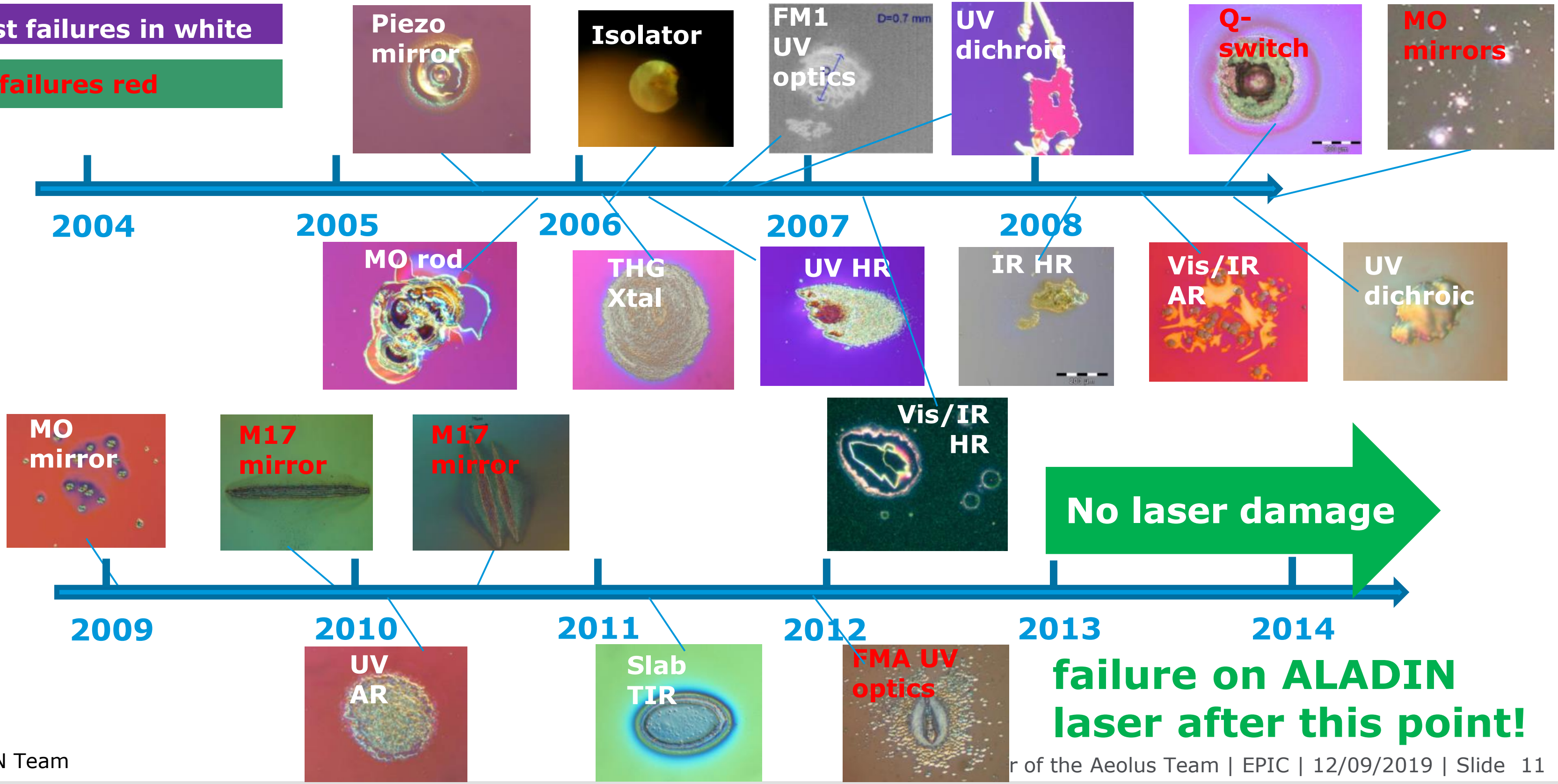


- Nd:YAG
- Diode pumped
- Wavelength 354.8nm
- Repetition rate 50.5Hz
- Emit energy 80mJ

(2) Aeolus – ALADIN (Atmospheric Laser Doppler Instrument)

Sample test failures in white

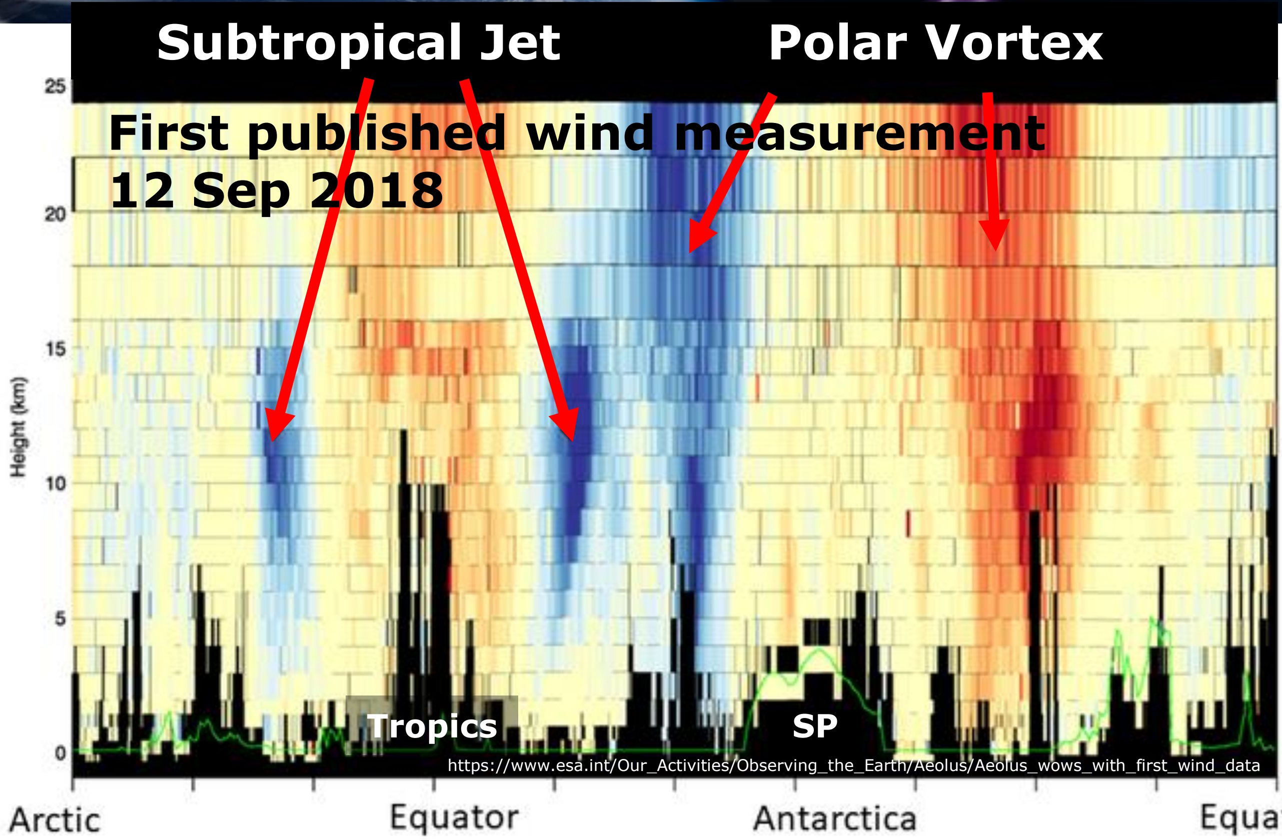
Laser test failures red



Courtesy of ALADIN Team

(3) Launch and first measurement

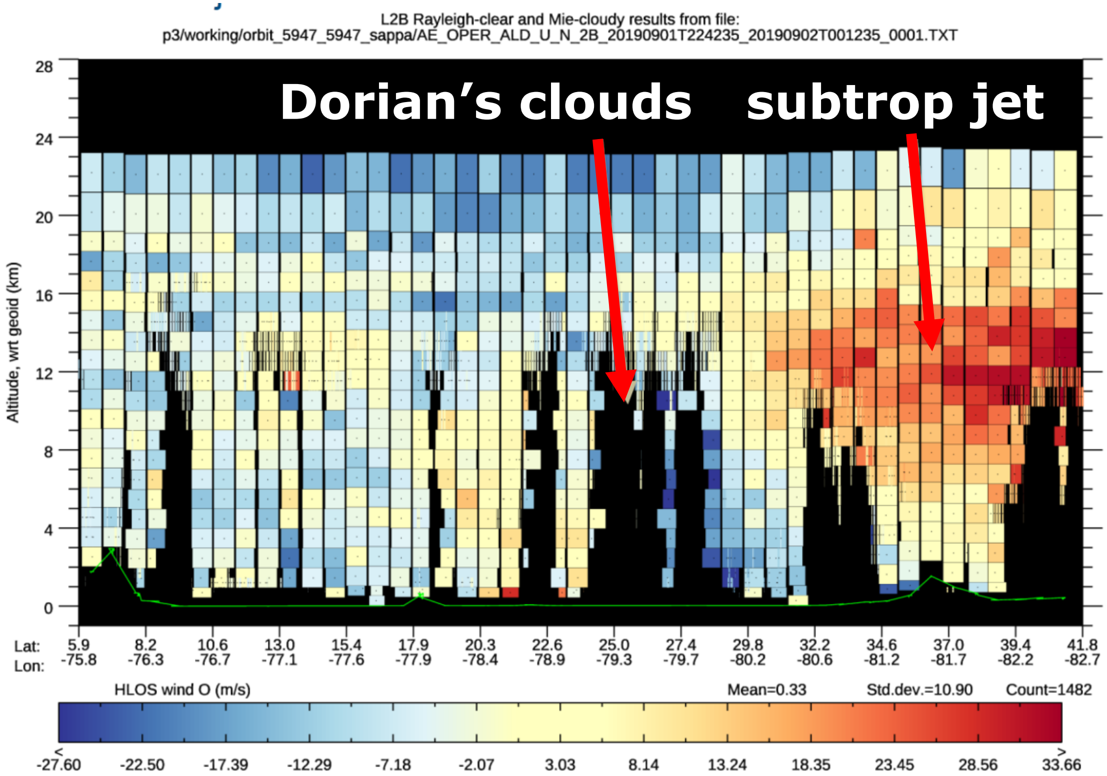
https://www.esa.int/Our_Activities/Observing_the_Earth/Aeolus/Watch_Aeolus_launch_replay



(3) Measurement example

Launch
22 Aug 2018

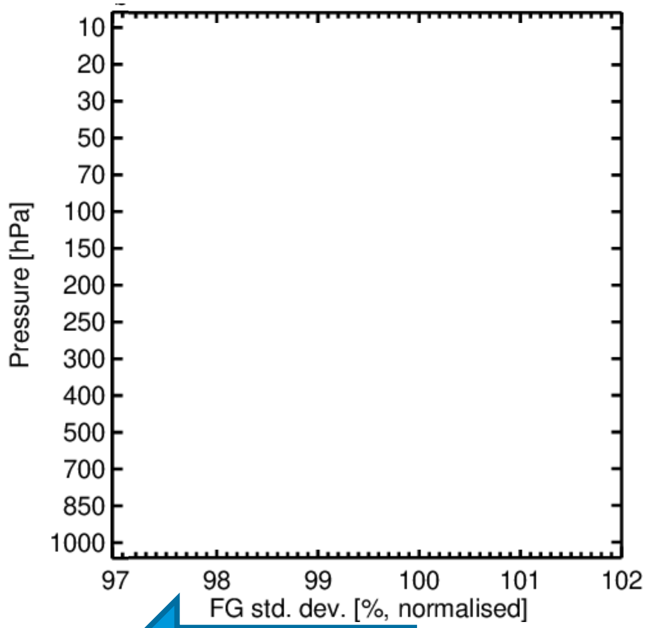
https://www.esa.int/Our_Activities/Observing_the_Earth/Aeolus/Watch_Aeolus_launch_replay



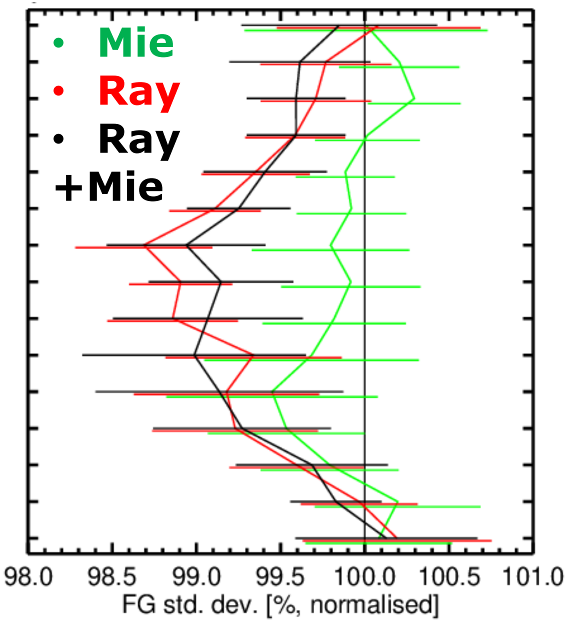
Courtesy of M. Rennie, ECMWF

(3) Fit of short-range forecasts to other obs.

Tropics, conventional (aircraft, radiosondes, profilers) wind



SH, conventional wind



better

Preliminary studies with short time series indicate **improvement in forecast**

- Tropics troposphere winds ~1-2% at day 1-2
- S. Hemisphere ~1-2% at day 1-2, 3% at days 4-6, and 5% at days 5-8

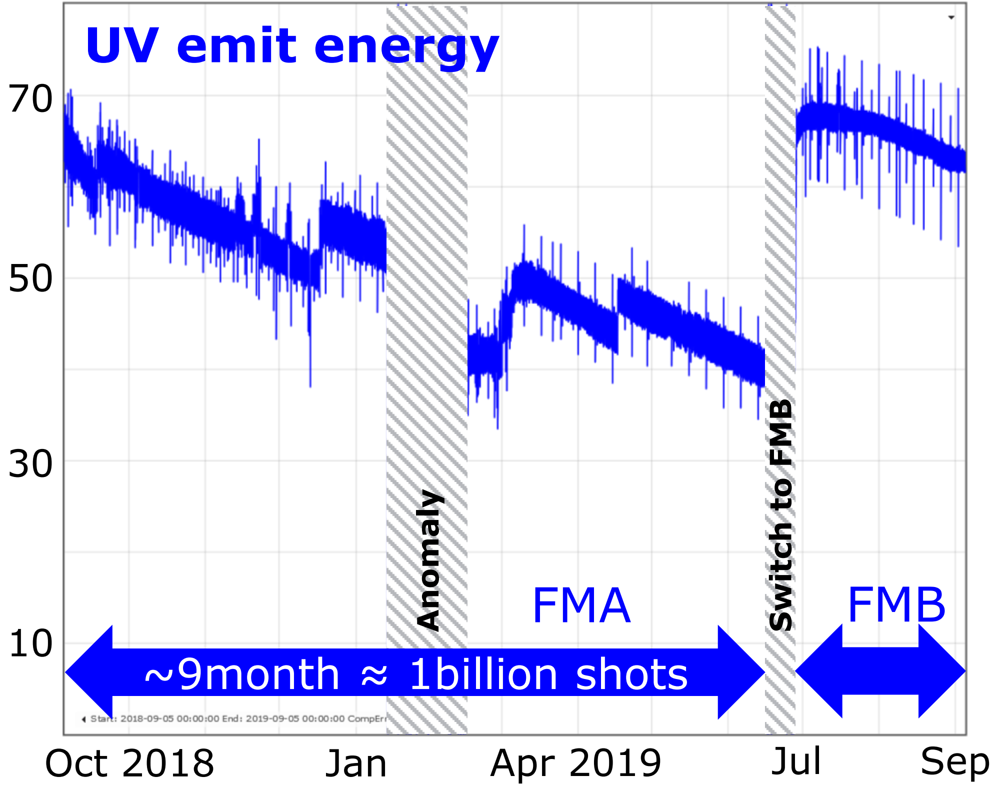
→ 2nd most important in SH!

~0.7% of 28M data

Courtesy of M. Rennie, ECMWF

(3) Inflight Observations:

(3) Inflight Observations: Emit Energy



Energy decrease

<u>FMA</u>

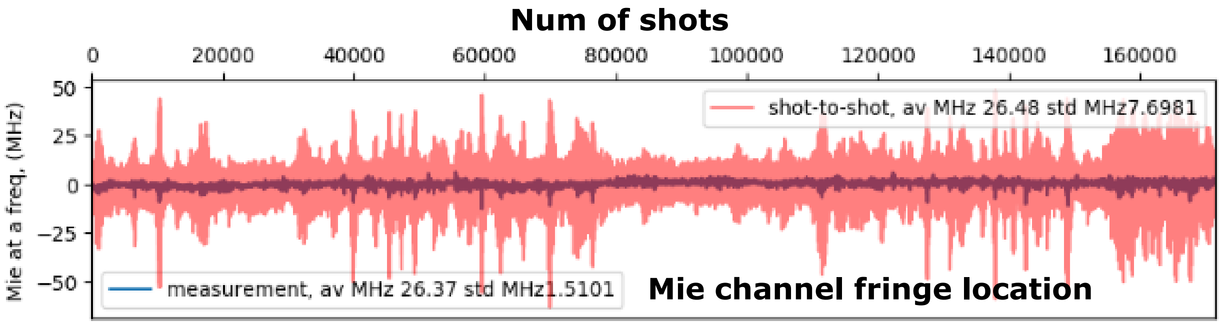
- Master oscillator alignment
- Photodiode calibration factor
- Laser diode degradation

→ Can be revisited later

<u>FMB</u>

- Under investigation

(3) Inflight Observations: Frequency Noise



Frequency noise

- 1 m/s ≈ 5.64 MHz
- 5-7 MHz rms achieved in orbit!

Courtesy of A. Ciapponi, ESTEC

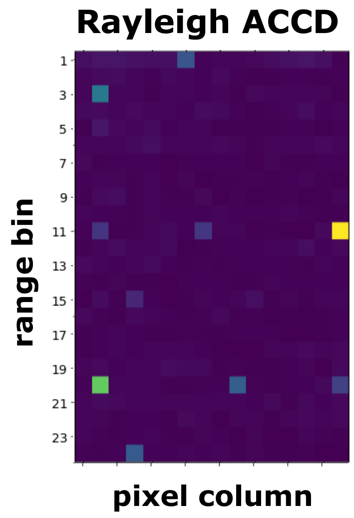
- (yet) uncorrelated time periods of increased frequency jitter (100MHz p-p)

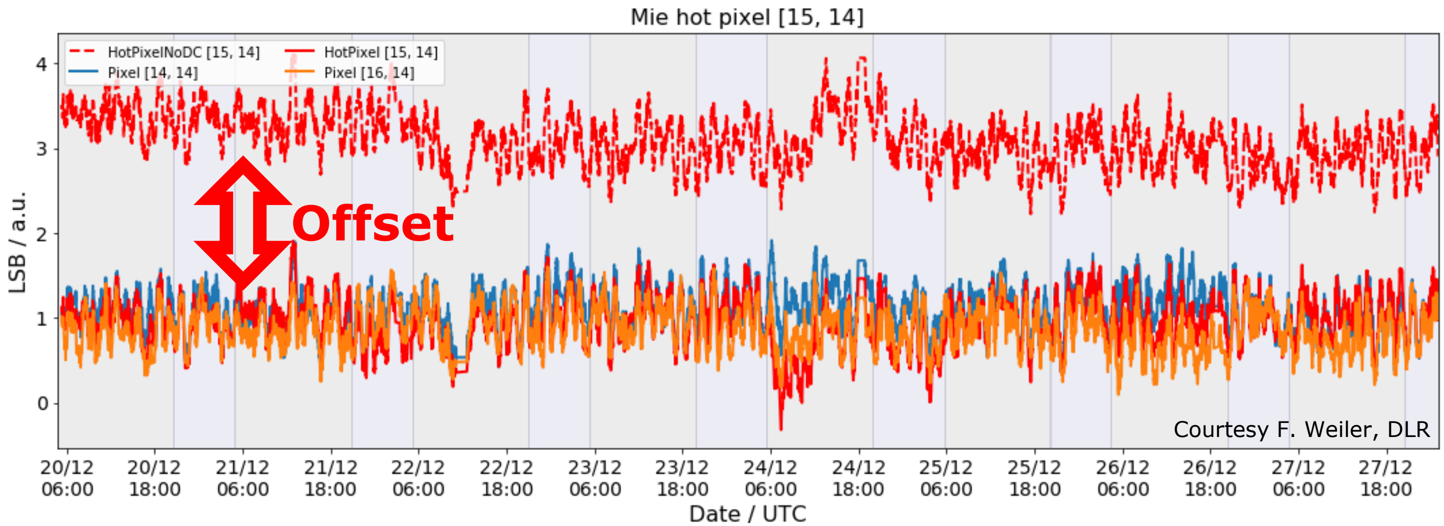
- Orbital variation found
- 11-15 MHz rms nadir attitude

(3) Inflight Observations: Hot Pixels

Hot Pixels

- Continuously increasing number of pixels show increased dark current
- Longterm in the order of 2-15LSB ≈2e-/shot, partially RTS signature





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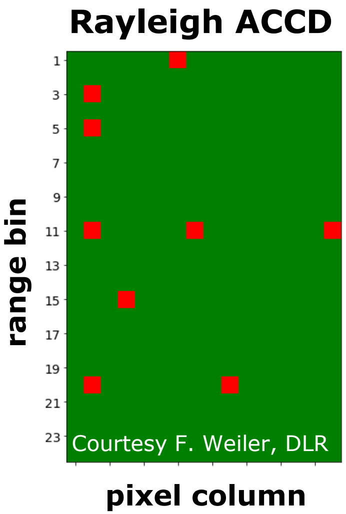
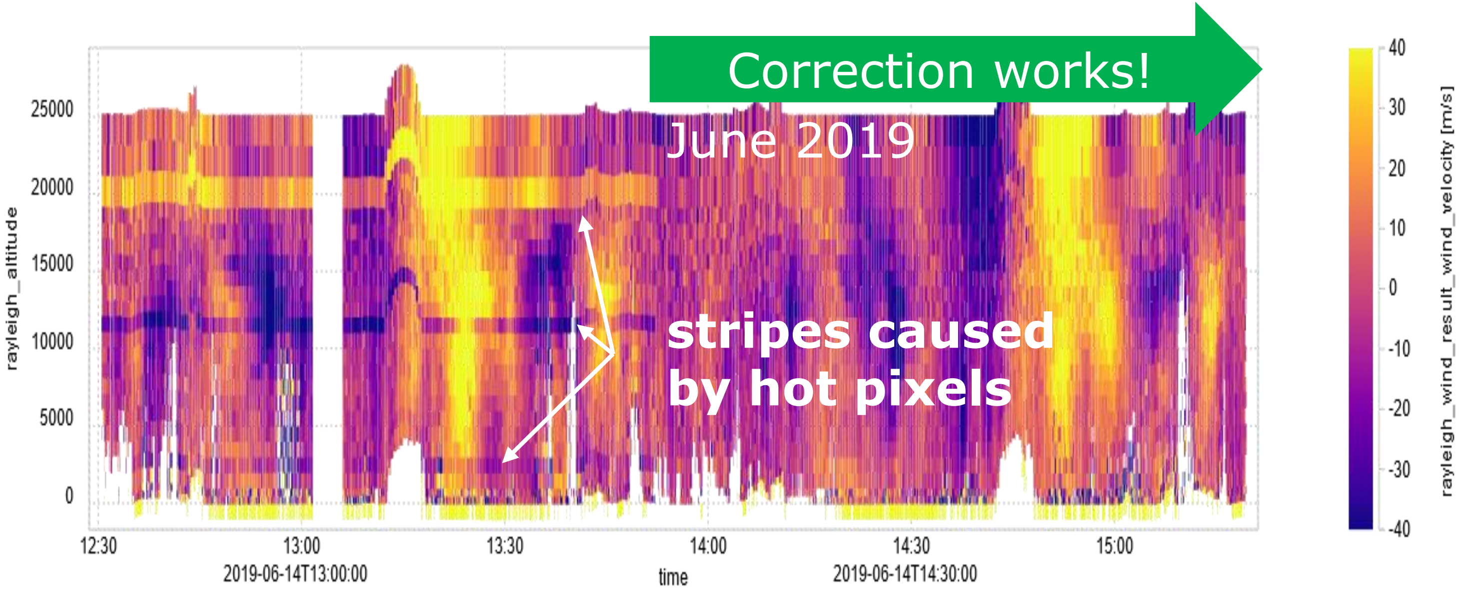
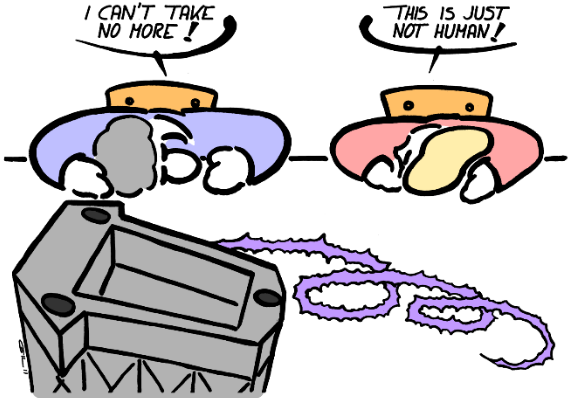


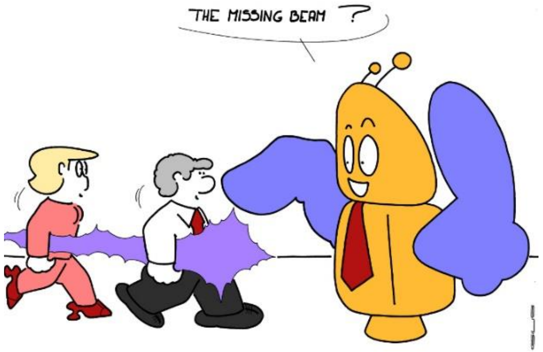


generated with VirES https://aeolus.services/

Summary

- ✓ More than 13 years of development <u>challenges</u>
- ✓ Invaluable <u>experience</u> has been gained, e.g.,
  - ✓ Laser thermal-mechanical design (energy, pointing drifts) and susceptibility of laser frequency to micro-vibrations
  - ✓ Optical component development and testing for high UV-energy lasers
  - ✓ Telescope thermal-mechanical design
  - ✓ Lidar system-level design (laser + optical receiver) and its representative end-to-end testing (OGSE as atmospheric simulator)





Summary

From a lidar-instrument perspective it was demonstrated that:

- ✓ a space-borne, direct-detection wind lidar can measure atmospheric winds by use of molecular Rayleigh and aerosol/cloud Mie backstatter => technical proof
- ✓ a powerful UV lidar can be operated in space over **12 months** with high frequency stability
- ✓ internal and atmospheric calibrations can be used to characterize the instrument including returns from the non-moving ground => bias corrections
- ✓ Positive impact on NWP according to first preliminary results as reported by various met centers

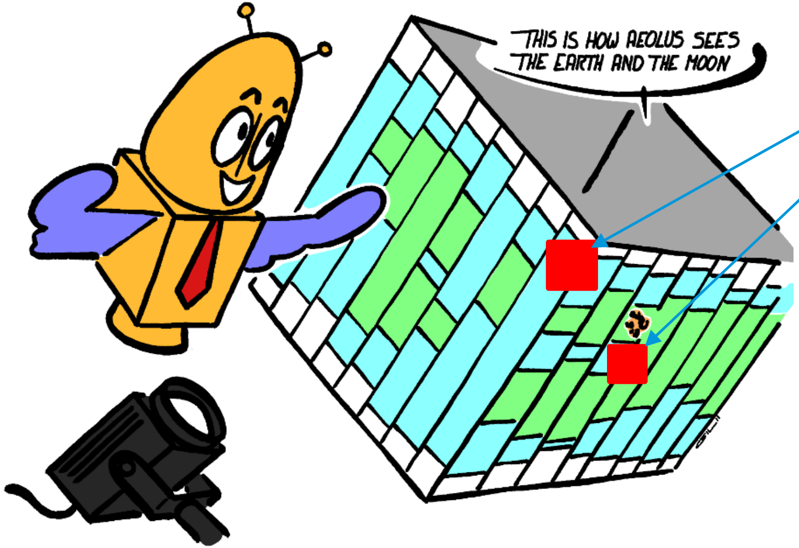
Thanks

esa

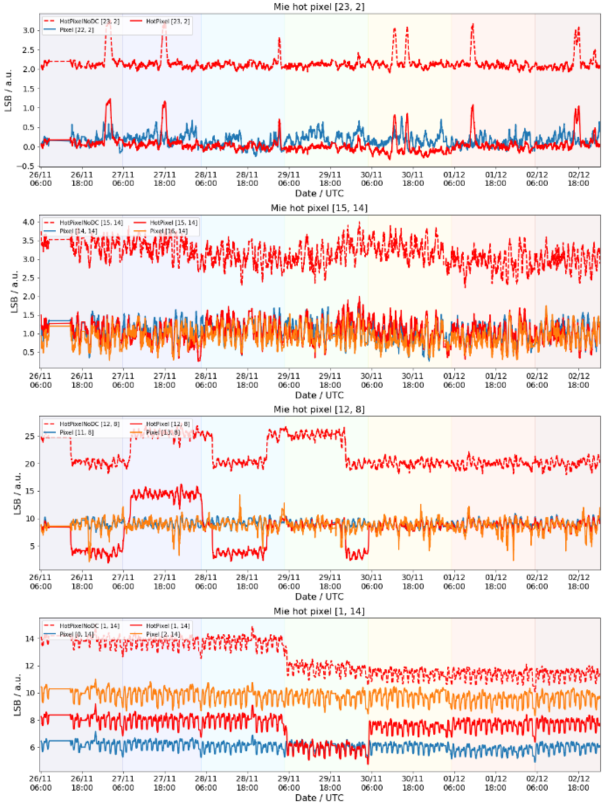
aeolus
because wind matters

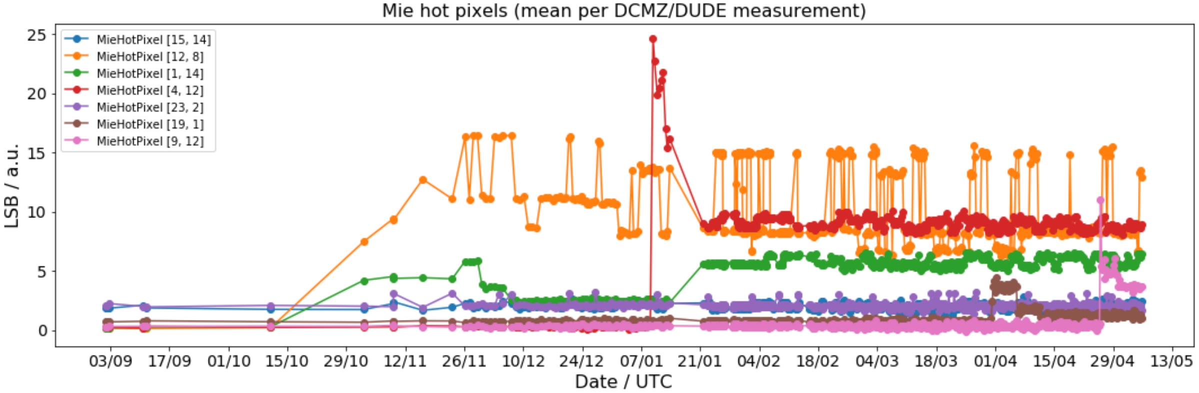
Aeolus – Range Bin Strategy

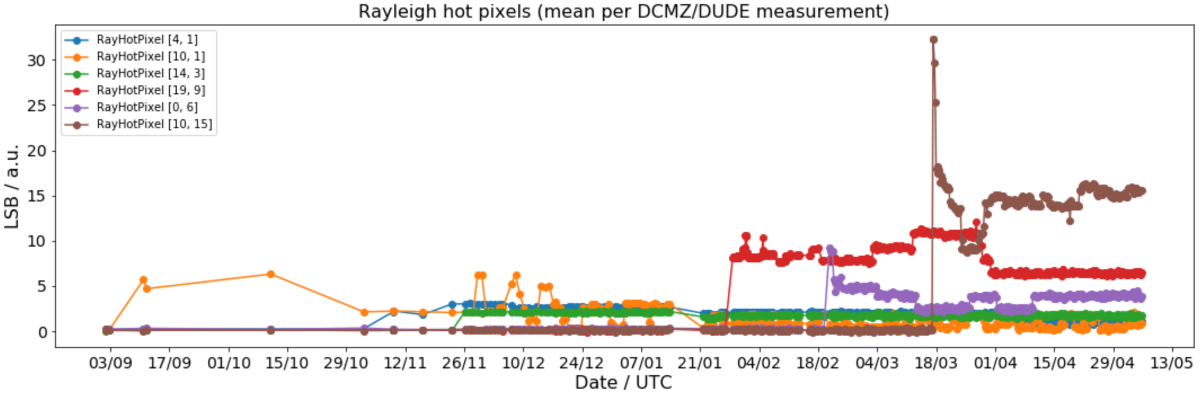
- Current settings will be kept global until October (data set July – Sep)
  - Northern Hemisphere + Tropics (+90 to -25deg latitude, stratospheric aerosol)
  - South Mid-Latitudes (-25 to -60deg)
  - South Pole (-60 / -90deg, PSC)



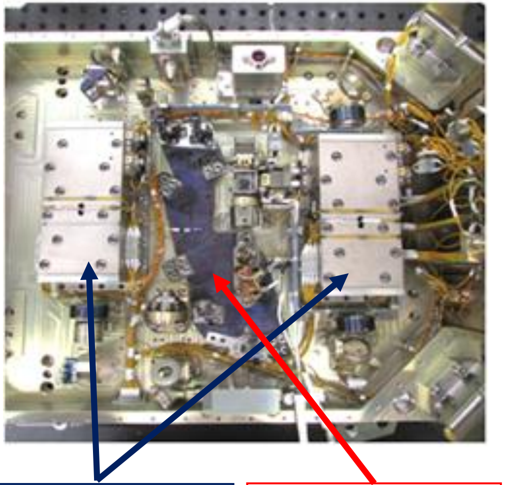
- Campaign boxes with specific settings added (Sep to October)
  (DLR-**AVATARI** around Iceland,
  East **M**editerranean **A**erosol **R**ange bin **S**ettings)
- Plans to perform special 3-week measurement period for AMV (Oct)
  (need 250m RBS in specific altitudes)
- New global settings Nov-Feb based on first feedback and for Strateole2
  (latitudinal belts 90-60-30deg)


Mie hot pixel [23, 2]
HotPixelNoDC [23, 2]
HotPixel [23, 2]
Pixel [22, 2]
LSB / a.u.
Date / UTC
Mie hot pixel [15, 14]
HotPixelNoDC [15, 14]
HotPixel [15, 14]
Pixel [14, 14]
Pixel [16, 14]
LSB / a.u.
Date / UTC
Mie hot pixel [12, 8]
HotPixelNoDC [12, 8]
HotPixel [12, 8]
Pixel [11, 8]
Pixel [13, 8]
LSB / a.u.
Date / UTC
Mie hot pixel [1, 14]
HotPixelNoDC [1, 14]
HotPixel [1, 14]
Pixel [0, 14]
Pixel [2, 14]
LSB / a.u.
Date / UTC


Mie hot pixels (mean per DCMZ/DUDE measurement)
MieHotPixel [15, 14]
MieHotPixel [12, 8]
MieHotPixel [1, 14]
MieHotPixel [4, 12]
MieHotPixel [23, 2]
MieHotPixel [19, 1]
MieHotPixel [9, 12]
LSB / a.u.
Date / UTC


Rayleigh hot pixels (mean per DCMZ/DUDE measurement)
RayHotPixel [4, 1]
RayHotPixel [10, 1]
RayHotPixel [14, 3]
RayHotPixel [19, 9]
RayHotPixel [0, 6]
RayHotPixel [10, 15]
LSB / a.u.
Date / UTC

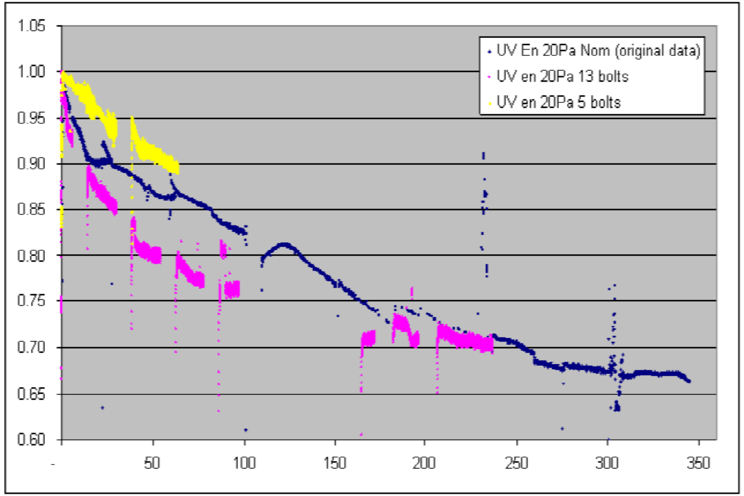
Major development lessons learned:
1) Changes of thermal interfaces in vacuum



Highly dissipative pump units

Highly alignment sensitive MO

Combining highly dissipative pump units and a highly alignment sensitive MO (without isostatic mounting) is simply not good design and should be changed



Relative energy evolution for different mechanical configurations of the Aladin laser pump units showing energy degradation of 30% over a few hundred hours (n.b. this only happens in vacuum when the pump units are ON). A residual element of this probably caused the energy loss on FM-A.

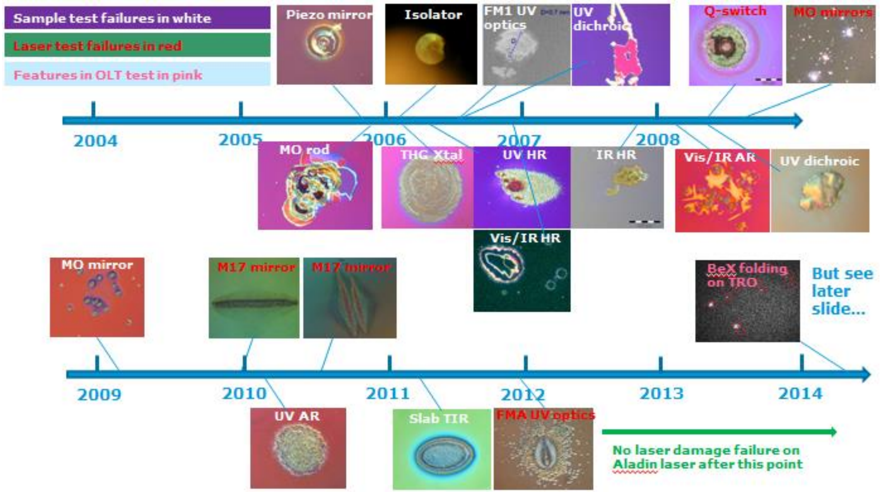
Lessons learned:

- ❑ Where possible remove units with high dissipation away from alignment sensitive components
- ❑ Attempt to minimize the mechanical constraints on the interface and/or the support structure for the alignment sensitive elements by making their mounts iso-static

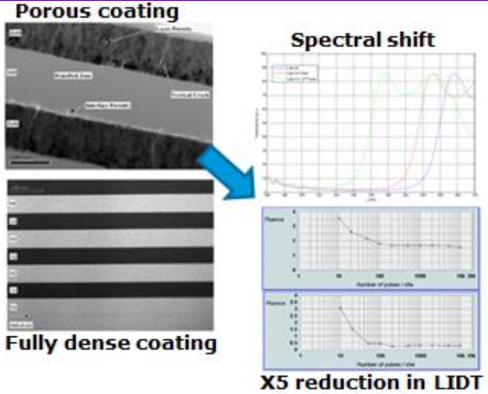
Design solutions:

- ❑ Use ATLID design (PU's moved away from optical bench) with additional pump unit with pre-demonstration that this improves the stability
- ❑ Improve the iso-staticity of the mounts

Major development lessons learned : 2) LID: control your processes and test as you fly



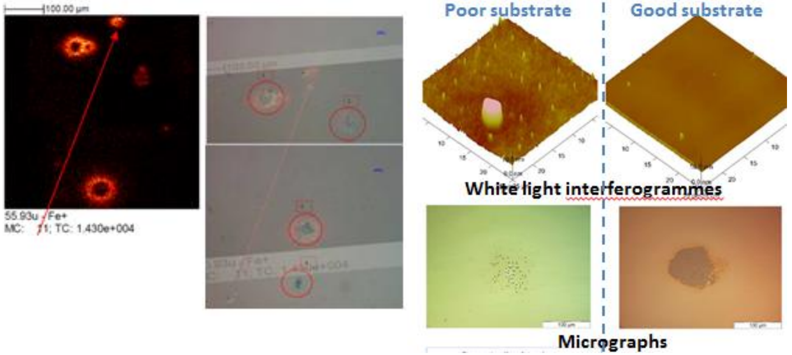
Laser-induced damage events during the Aladin laser development



Porous coatings release water in vacuum leading to a spectral shift (due to effective refractive index change) and a massive reduction in the laser damage threshold (due to generation of tensile stress in the coating)

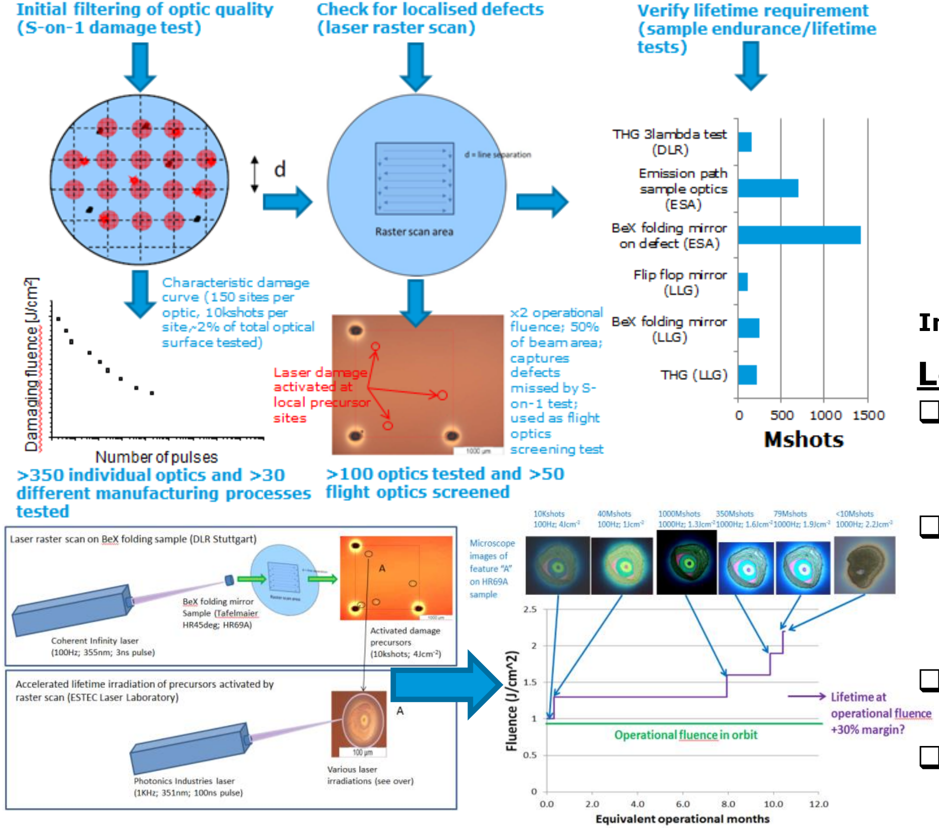
<u>Lessons learned:</u>

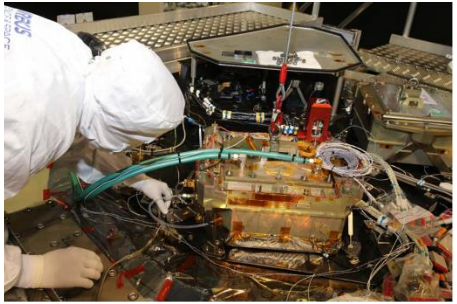
- ❑ **If you operate in vacuum, test in vacuum**
- ❑ **Use fully densified coatings**
- ❑ **Use processes that inherently reduce the number of small defects on both substrates and coatings**
- ❑ **Ensure adequate physical-chemical analysis is undertaken to avoid potential problems and control processes**



Small defects can lead to damage after 10's of Mshots and they can arise from many sources

Major development lessons learned : 3) LID: you are only as good as your weakest optic

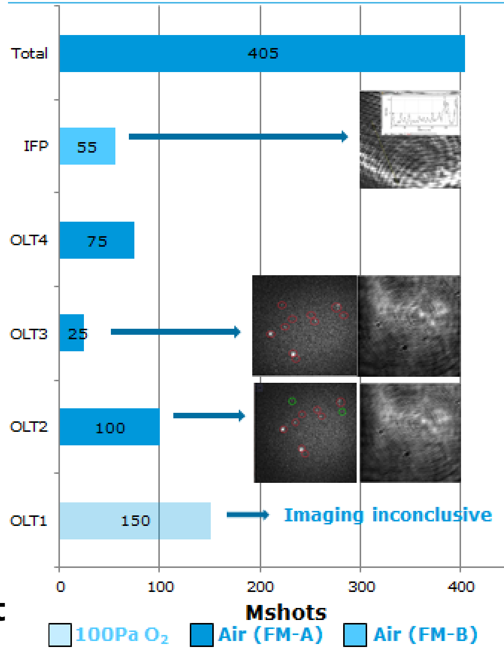




Instrument level testing with FM-A

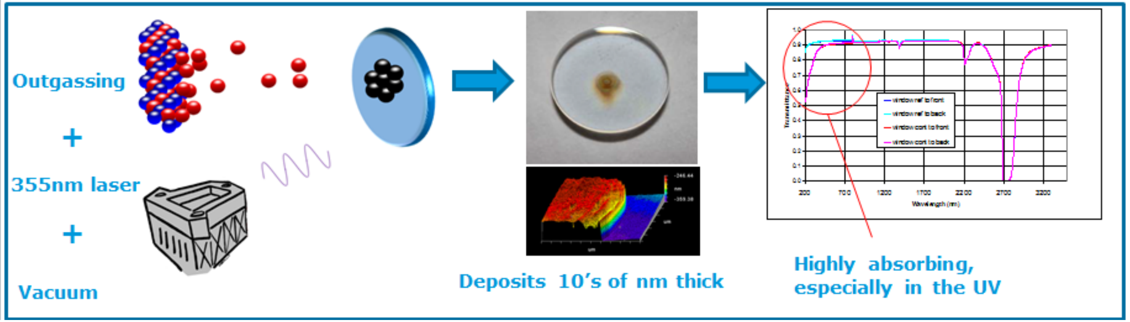
Lessons learned:

- ❑ Test the full area of the optic which contains the beam
- ❑ If damage precursors are activated then perform test directly on the defect to ensure it will be stable
- ❑ Test for an adequate number of shots
- ❑ Ensure there is a margin on LIDT by > x2

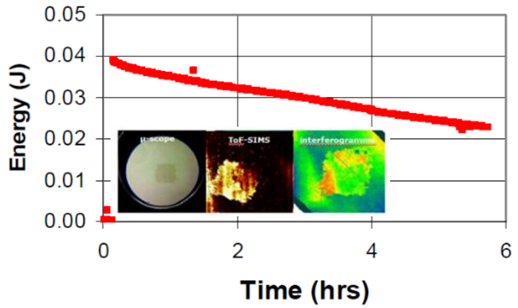


Instrument level testing of the weakest optic in the emission path

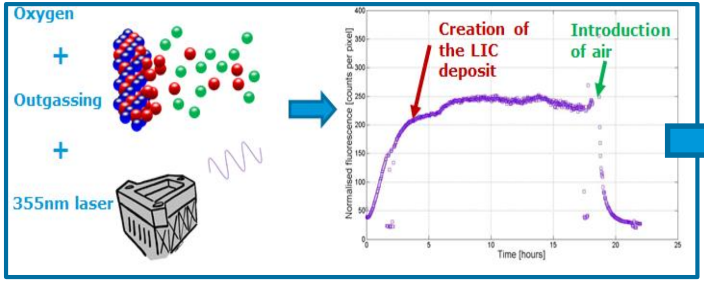
Major development lessons learned :
4) You need some oxygen to prevent LIC



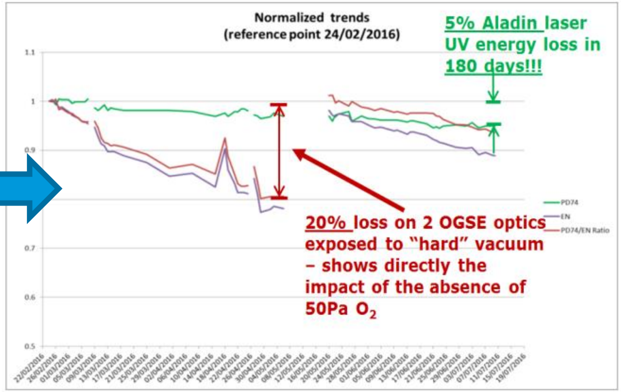
LIC: highly absorbing deposits formed by the interaction of the laser with organic outgassing on the surface of optics



Loss of 50% of the energy of the Aladin EM laser vacuum test after 6 hrs (not good for a 3yr mission)



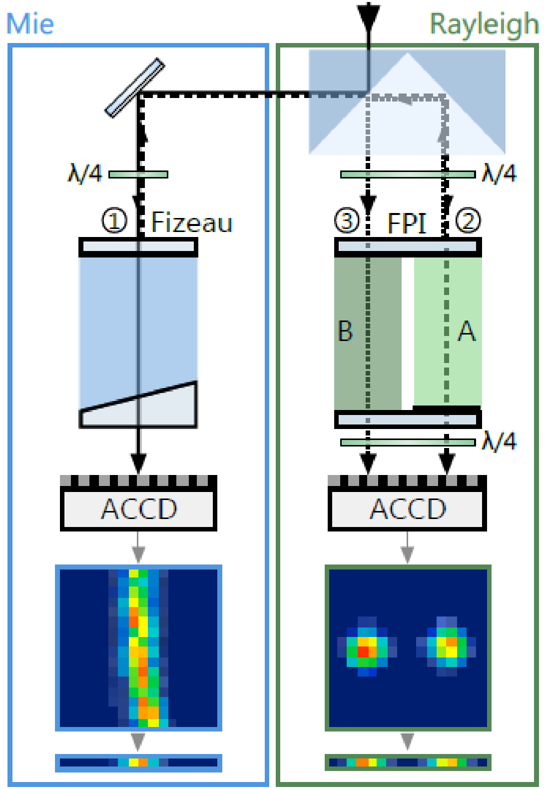
Introduction of O_2 eradicates LIC



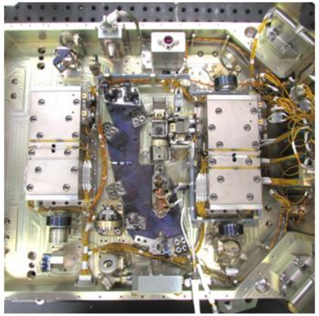
Loss of 5% energy after 6 months

Lessons learned:

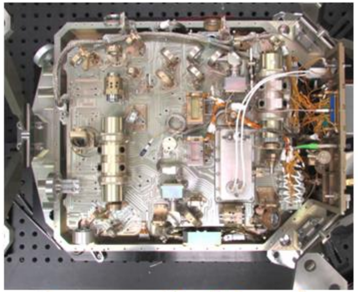
- ❑ Classical contamination control methods do not stop LIC but still mitigate its effect
- ❑ Get rid of "bad" materials (silicones, aromatics,... as far as you can)
- ❑ High power lasers need an oxidising environment to operate in



Lux et al., 2018



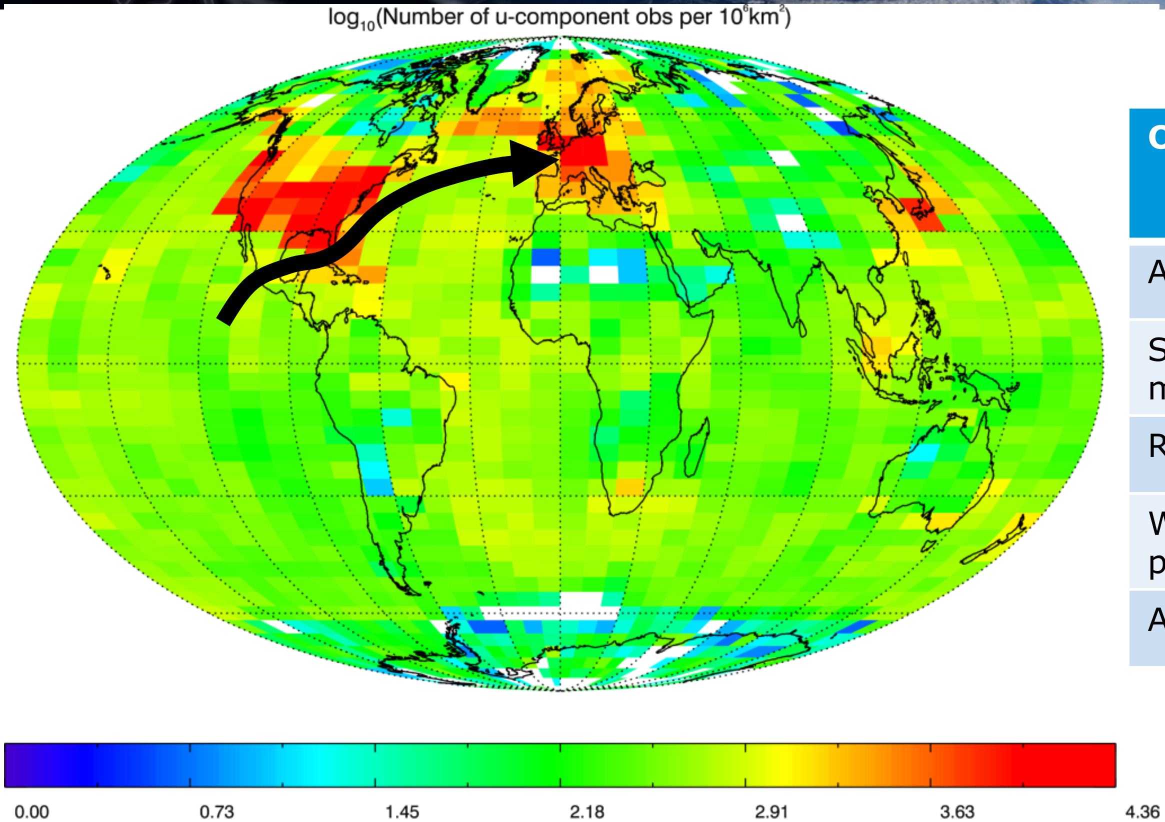
Upper optical bench



Lower optical bench

Parameter	Value
Dimensions	(582x422x215)mm
Volume	30L
Mass	30Kg
Power consumption	300W
Wavelength	354.8nm
Pulsewidth	20ns (FWHM)
Pulse repitition frequency	50.5Hz
Energy (IR)	280mJ
Energy (UV)	80mJ
Harmonic section conversion efficiency	28%
Peak fluence (UV)	$1 Jcm^{-2}$
Wall plug efficiency (UV)	1%

(1) Wind information in recent ECMWF cycle

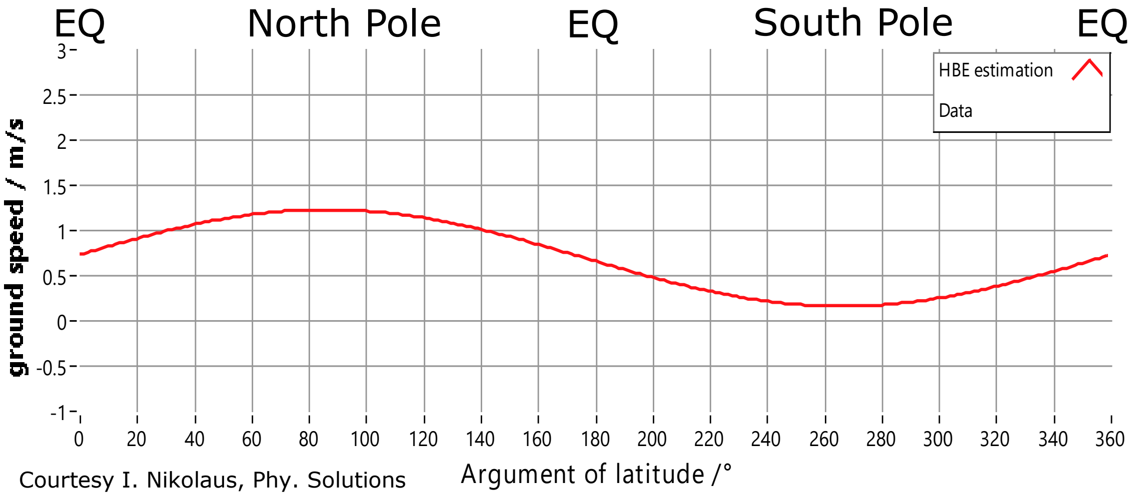


Obs type	% of total count	Mean assigned u-wind error (m/s)
AMVs	47	4.6
Scatterometer	23	1.5
Radiosondes	11	2.0
Wind profilers	10	1.8
Aircraft	9	2.4

Rennie, 2014

Harmonic Bias

- Orbital cycle of satellite to surface distance and thermo elastic variations result in harmonic residual of the “zero wind” surface return



Courtesy I. Nikolaus, Phy. Solutions

- Seasonal variation
- Introduce bias up to ±6m/s that can be corrected to about 1m/s
- Non-orbital biases under investigation

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